(Ballion), which can be distinguished by the male genitalia (Green, 1979) (Fig. 1). Captures were particularly abundant from June to September. These species are considered secondary pests affecting stored grain, processed dry foods, and animal feeds. Some other pest species were captured with both type of traps, including the Coleopteran *Anthrenus* sp., *Sitophilus* sp., *Rhyzopertha dominica* (F.), *Oryzaephilus* sp., and *Tribolium*. sp. According to our results, the presence of *T. granarium* in the sampled areas is not confirmed. Therefore, this species does not seem to be established in Spain.

Fig 1. Male genitalia of *T. inclusum* (left) *T. variabile* (center) and *T. granarium* (right):

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Performance Assessment off a Commercial Scale Solar Biomass Hybrid Dryer for Quality Seed Maize Production

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DOI 10.5073/jka.2018.463.012

Abstract

Though several maize varieties have been developed and introduced over the years in Ghana, farmers still face challenges of access to quality seed maize. Among the major constraints is lack of proper drying systems to guarantee quality of seed produced. Peculiar to most parts of Africa, drying of maize in the open, on bare ground along shoulders of roads is still a common practice in Ghana. In this study, a 5-tonne capacity solar biomass hybrid dryer was developed for drying maize for seed and food/feed in Ghana. Effect of drying air temperature in the dryer on the physiological quality and germination of maize kernels was investigated. Maize grains were dried in the open sun simulating farmers practice and using the dryer at 4 varying levels (L1, L2, L3 and L4) with corresponding heights (0.6m, 1.2m, 1.8m and 2.4m) respectively. Harvested maize at 22.8% moisture content was dried at the varying levels until reaching overall mean moisture content of 12.8 ± 0.2% (wb). Results showed that, drying air temperatures in the dryer increased in accordance with height with lowest mean temperature of 44.4 ± 4.6˚C recorded at L1 and mean maximum of 52.8 ± 5.4 ˚C at L4. The increase in drying temperature at L4 increased kernel stress crack index by an average of 14% and reduced germination by 33%. However, drying temperatures at L1-L3 and in the open sun had no significant effect ($p > 0.05$) on the germination potential of maize grains. This satisfies the dryer's potential to be used for drying maize grains for high quality seed production on commercial scale.

Keywords: Solar biomass hybrid dryer; drying; maize grain; germination.

1. Introduction

Maize (*Zea mays*) is an important cereal food crop extensively cultivated worldwide for food and as livestock fodder. In Ghana and sub-Sahara Africa, maize is the most important cereal crop produced and is also the most widely consumed staple food. The production of maize in Ghana is dominated predominantly by small-holder resource poor farmers mainly under traditional production practices and rain-fed conditions resulting in yields well below attainable levels (Amanor-Boadu, 2012). Maize yields in Ghana average approximately 1.9 metric tonnes per hectare, however, achievable yields as high as 6 metric tonnes per hectare are possible, if farmers use improved seeds, fertilizer, mechanization and irrigation (MoFA, 2013). However, availability of quality improved seeds is one of the main challenges faced by farmers in Ghana resulting in their over reliance on their own seed stock for production. After harvest, it is common for maize grains to have moisture contents considered inadequate for safe storage for seed. Under such situation, there is clearly a need for reduction of this characteristic to preserve the physiological quality of seeds for at least eight months, impeding possible chemical and physical changes that may come about during storage up to sale of the seeds (Carvalho et al., 2016). Drying maize after harvest from high moisture content (20-30%) to low safe storage moisture content (12-14%) is therefore necessary to ensure storability and preservation of maize grains as seed lots in warm and humid countries like Ghana. Post-harvest activities such as drying and storage are among the key areas along the maize value chain that is of critical importance to small-holder farmers/traders in Africa (Akowuah et al., 2015). However, traditional drying methods where farmers rely on leaving their crops to dry in the field or in the open sun next to farmers' homes or along shoulders of roads either on bare ground or on tarpaulins are unhygienienic and can be detrimental to the quality of the dried seed grain. During unfavorable weather condtions, drying can take up to 10 to 14 days before a safe storage moisture content of 12-14% is reached. Inadequate drying especially among peasant farmers in rural communities poses a serious threat to food safety and security in Ghana, since it creates favourable conditions for fungal growth and insect damage during storage (Folaranmi, 2008) leading to substantial losses grains for seed or food. A significant percentage of the current post-harvest losses and aflatoxin contamination can be attributed to improper and/or inefficient drying of foodstuffs such as maize and groundnuts (Togrul and Pehlivan, 2004). However, the introduction of heated air mechanical dryers is not desirable by most small-holder farmers in Ghana due to high drying charges. Also, drying air temperatures as high as 70 -100 ˚C may be reached with these dryers. These temperatures are considered excessive by most farmers for seed drying. The most severe constraints are on beans (35 ˚C), rice (45 ˚C), and all grains if they are to be used for seed (45 ˚C) (Weiss and Buchinger, 2015). The viability of grain is therefore directly linked to the temperature attained during drying. Seed embryos are killed by temperatures and therefore for seed grains, low temperature drying schemes must be used. Seed grain may be dried in any type of dryer provided it is operated at a low temperature and preferably with high flow rates than generally used (Weiss and Buchinger, 2015). Hassan (2010), reported maximum average germination percentage and viability of dried paddy seed of 86% and 98% respectively after drying paddy seeds at 44 ˚C in a hybrid solar drier. Tonui (2014), attested to the effect of rapid drying under high temperatures in mechanical drying which often results in stress cracks, reduction of the milling quality of grains, discolouration and reduced germination potential. Fast drying due to high temperature are also likely to induce seed cracking including internal fissures due to trapped moisture. Conventional solar dryer's may be a solution to these challenges but due to its high weather dependency, its usage is limited during rainy periods, cloudy weather conditions and at night. Due to this, the commercialization of solar dryers has generally not been successful leading to limited or non adoption of such systems by farmers in Ghana (Sekyere et. al., 2016). However, Kaaya and Kyamukangire, (2010) reported that, maize grain dried using biomass-heated natural convection dryer did not significantly reduce the kernel viability.

In this study, the performance of a 5-tonne capacity solar biomass hybrid dryer (SBHD) that integrates both solar and biomass energy for seed maize drying on commercial quantities is investigated. Specifically, effect of drying temperature on germination rate and stress crack on grains were determined.

2. Materials and Methods

The experiment was conducted in January, 2017 using a 5-T capacity SBH dryer purposely constructed for a commercial seed maize distributor at Wenchi in the Brong Ahafo Region of Ghana.

2.1 Dryer Description

Fig. 1 shows the chematic and constructed views of the 5-tonne capacity SBHD at the site. The SBHD is based on a greenhouse structure design with an overall dimension of 10.7 × 6.5 × 3.3 m. It is partitioned inside into three drying sections i.e., the Right Section (RS), Left Section (LS) and a Middle Section (MS). Each of these stations have four levels of drying shelves/racks. The drying shelves are arranged from top to bottom in order of Level 4 (L4), L3, L2 and L1 respectively. The dryer is coupled with a biomass burner enclosed with a crossflow type heat exchanger to raise the temperature of ambient air that is blown into the SBHD with a 0.374-kW axial-flow fan that draws in drying air through the heat exchangers and passes it through the drying beds. The SBHD was test-run during the minor maize production season under load conditions during the month of January 2017 which is one of the driest month in the year.

***Fig. 1**: Solar Biomass Hybrid Dryer; schematic view (left) and constructed view (right)*

2.2 Experimental Procedure and Setup

To assess the performance of the SBHD, white shelled maize at 22.8 % moisture content wet basis was obtained from a local farmer and dried in the dryer and in the open sun. Drying occurred using experimental cages (0.3m × 0 .3m × 0.05m). Each cage was filled with maize seed samples weighing 1kg and were replicated three times at each level within the dryer. A control set-up of equal maize seeds (1kg) in triplicate was also dried in the open sun as practiced by most rural farmers in the area. The experimental trays containing the maize samples were taken out every hour and weighed to monitor the moisture reduction of the maize samples. The moisture content at the i^{th} time during the drying period was calculated using Euqtaion 1 until the required final moisture content was attained.

Moisture content (%); $MC_i = (1 - W_o \frac{(1-Mo)}{Wi})$ ………………….. Equation 1

MC_i = moisture content at i^{th} time (%)

M_o = initial moisture content in decimal

W_o = initial weight of samples in grammes (g)

W_i = weight of samples at ith time in grammes (g)

The drying process started at 09:50 am to 16:50 pm, over a period of seven (7) hours. During this period, Tinytag TGP-4017 data loggers (Gemini Data Loggers, Chichester, U.K.) were installed near the experimental cages to monitor and register variations in heat and humidity in the drying environment. Five data loggers were positioned, as shown in Fig. 2, at each of the four levels and the average used to represent the drying conditions at each level. Drying conditions in the dryer were compared with the ambient conditions.

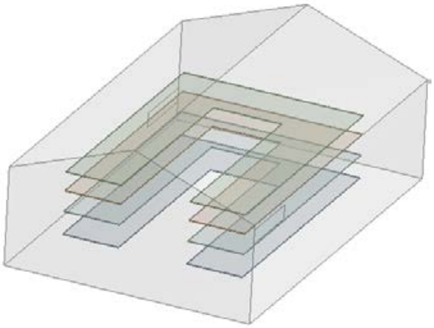
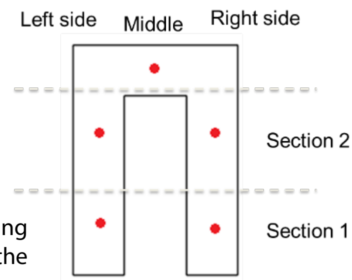


Fig. 2: Drying levels and data logging positions in the dryer



2.3 Germination Test

The germination test was carried out in accordance with the criteria established in the Rules for testing seed (ISTA1985). Four 100-seed sub-samples for each drying level and the open sun were randomly selected and planted in germination trays fill with soil fetched from a river bank. The setup was kept under room temperature conditions. Emergence counts started from the fifth day after planting and continued on the sixth and seventh days. The percentage of normal seedlings was calculated eight days after the test was set up. The percentage germinated seeds were calculated using Equation 1 as stated by Azadi and Younesi (2013).

$$\%\ \text{Germination} = \frac{\text{number of seeds germinated}}{\text{number of seeds set for germination}} \times 100\% \ldots \ldots \ldots \ \text{Equation 1}$$

2.4 Stress Crack Test

Maize grains were selected by random sampling from each station per layer of dried grains. For each sample, 100 seeds free from insect attack were counted and analysed for stress cracks. The samples were placed on a light box and checked for single, double, multiple or no cracks. The stress crack index (SCI) for each of the analysed sample was determined using Equation 2 as proposed by Kirleis and Stroshine (1990).

$$\text{SCI} = (1 \times \text{single crack}) + (3\ \times \text{double crack}) + (5\ \times \text{multiple crack}) \ldots \ldots \ldots \text{Equation 2}$$

2.4 Data Analysis

The experiment was conducted in a complete randomized design and data obtained were subjected to analysis of variance (ANOVA) using GenStat statistical software version 12 at a significance level of 5% (p≤0.05). Results were presented in tables and graphs using Microsoft Excel using the mean values obtained.

3. Results

3.1 Temperature variations during drying

The temperature profile recorded during the drying of the maize grains for seed in the SBHD is presented in Fig. 3. Drying air temperature at level 4, increased during the first four hours, from 41.1 ˚C to a maximum of 58.9 ˚C by noon and reduced to 43.2 ˚C at the end of the drying process. Over the drying period of 7 hours, a mean temperature of 52.8 ± 5.4 ˚C was recorded at L4. Similar variations in temperature trend were oberserved for L3, L2 and L1 in the dryer with mean temperatures of 49.8 ± 5.6˚C, 45.4 ± 5˚C and 44.4 ± 4.6˚C respectively. Comperably, the overall mean temperature inside the dryer (L1-L4) of 48.1 ˚C was higher than the ambient temperature by 12 ˚C. This could be attributed to the solar insolation during the time of the experiment (Tibebu et.al, 2016). Also, the hot air from the biomass furnace rises due to the force convection from the blower with the heat accumulated at the upmost part of the dryer leading to the recorded higher temperatures at L4.

3.2 Changes in maize grain moisture content during drying

As the drying temperatures increased, the moisture content of the maize grains reduced. Maize grains at 22.8% moistute content was dried to an overall final average moisture content of 12.8± 0.2% (wb) within 7hrs. However, samples at L4 and L3 reached average moisture content of 13% within 5 and 6hrs of drying respectively while samples at L1 and L2 reached final moisture content of 12.7% by the 7th hour. Comparably, samples dried in the sun reduced from 22.8% to 12.9% in 7hrs. The result showed that overall drying rates of 1.3%/hr were acheievd in the dryer compared to 1.2%/hr for samples dried in the open sun. The high moisture reduction rate achieved in the dryer could be attributed to the additional heat from the biomass furnace attached to the dryer which facilitated the faster drying of grains to the required moisture content. Fig. 4 shows the variation of moisture content of maize samples dried at different levels in the SBHD as compared to the samples dried in the open sun.

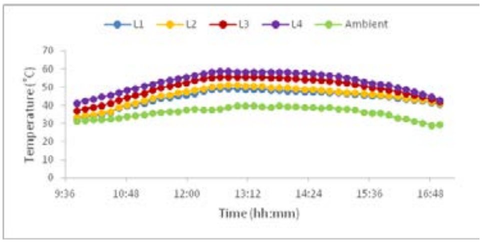


Fig. 3: Temperature trend at different levels in the SBHD vs ambient

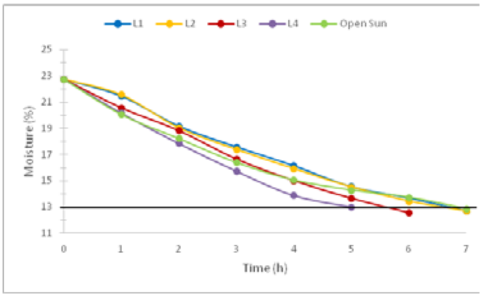


Fig. 4: Moisture content across levels in the SBHD vs open sun

3.3 Effect of drying temperature in SBHD on maize kernel viability

Drying maize using the SBHD did not significantly reduce the viability of the kernels. However, there was a 9% reduction in overall germination potential of grains dried in the SHBD compared to grains dried in the open sun. From the temperature effect, it was observed that, due to the increase in temperature of drying air at the upper level (L4) of the SBHD, the percentage of normal seedlings decreased compared to the lower levels (Table 1). Germination rate of grains dried at various levels with mean temperaures of 52.8 ± 5.4 ˚C, 49.8 ± 5.6˚C, 45.4 ± 5˚C and 44.4 ± 4.6˚C were 44, 61, 64, and 78% respectively (Table 1).

Tab. 1: Percentage germination of maize dried using SBHD*

Layer	Mean temperature (˚C)	Germination (%)
Level 4	52.8 ± 5.4	44 c
Level 3	49.8 ± 5.6	61 b
Level 2	45.4 ± 50	64 b
Level 1	44.4 ± 4.6	77 a
Open Sun	35.99 ± 3.2	71 ab
LSD (p≤0.05)		11.95

*Within a column, means followed by the same letter are not significantly different (P>0.05)

3.4 Stress Crack Analysis

Percent stress-cracked kernels in different categories for maize grains dried at the various levels in the SBHD are presented in Table 2. It was observed that, there was much variation among the different stress-crack categories for grains dried at the different levels in the dryer. In all categories, grains dried at level 4 (L4), had higher stress crack values compared to grains dried at L3, L2, L1 and the open sun. Among the stress-crack categories, the percentage multiple stress cracks were the lowest at all the levls followed by the doubles and the singles in that order. To establish variations in drying temperature effect on the quality of the grains, the SCI was determined for grains dried at the various level. As shown in Table 2, the highest SCI of 160 was recorded for Level 4 followed by L3, L2, L1 and the open sun with SCI of 70, 24, 22 and 14 respectively

Tab. 2 shows the stress crack analysis for the dried samples at each level comapared to the samples dried in the open sun. It is revealed that temperature has an effect on the final quality of the dried maize in terms of the grains susceptibility to cracks. Samples at L4 had the highest stress crack index (SCI) of 160 due to relatively high average temperature experienced at that level during the trial. This high SCI value indicates a high susceptibility of grains dried at L4 to cracking. With relatively low temperatures experienced in the ambient, low SCI value of 14 was observed.

Tab. 2: Stress crack analysis of sampled maize at different levels

Level	Stress Crack Categories				SCI
	No crack (%)	Single (%)	Double (%)	Multiple (%)	
Level 1	90	5	4	1	22
Level 2	90	4	5	1	24
Level 3	68	18	9	5	70
Level 4	38	26	23	13	160
Open Sun	94	2	4	0	14

4. Discussions

The maximum temperature recorded during drying in the SBHD was 58.9°C which was recorded after 4 hours at the top shelve (Level 4). Similar temperature recordings of 55.8, 51.1 and 49.4 °C were recorded for the lower drying shelves (L3, L2, and L1) respectively. Comparably, ambient temperature of 39°C was recorded at the same time. The high temperatures recorded in the dryer compared to the ambient temperature could be attributed to the transparent cover material used in construction of the SBHD which has the ability to retard the heat from escaping by acting as a heat trap for infrared (thermal) radiation thereby forming a confinement for the heated air. Similar results were obtained by Achint et al., (2017) during corn drying in a solar cabinet dryer. The additional heat from the biomass furnace also contributed to the high temperature trend in the dryer compared to the ambient temperature agreeing with the findings of Kaaya and Kyamuhangire (2010).

In the solar biomass hybrid dryer, as the drying temperature increased the drying time and grain moisture content decreased irrespective of the grain position (L1 –L4) in the dryer. Mean moisture content decrease steadily from 22.8% to 12.2% (wb) during the 7 hour drying period. This agrees with the findings of Agona et al., (1998), who reported that drying of maize cobs in a biomass natural convection dryer takes between five and six hours to reduce the moisture content to 14%. Similar results were also obtained for the drying of eggplant (Ertekin and Yaldiz, 2001), and coroba slices (Corzo et al., 2010).

The effect of temperature across levels on the stress crack of the dried maize grains was distinct. Increase in drying air temperature across the drying trays/shelves in the SBHD did not significantly affect the quality of grains dried at the lower shelves with only 10% of grains samples dried at L1 and L2 showing visible signs of stress cracks. However, grains dried at the top tray (L4) had over 60% of dried grains samples showing visible signs of stress cracks with about 50% recorded under the single or double stress crack category and little over 10% found in the multiple range category. The maximum grain temperatures reached in the dryer at the top trays (L4) may have contributed to this occurrence. Similar works (Lewicki and Pawlak, 2003; Sadjad and Saeid, 2014) have showed similar results where increase in drying temperature increased moisture gradient, creating internal tensions, cracks, breakages, and fractures in dried corn. Chakraverty (1988), also reported that these changes create internal stresses, resulting in cracks, which lead to damage and fractures in the structure of agricultural products.

Evaluation of seedling performance also manifested the negative effects of increase in drying temperature on the physiological quality of maize seeds. It was observed that, maize grains dried at the upper level (L4) of the SBHD where the highest mean temperature (52.8 ± 5.4 ˚C) and highest SCI (160) where recorded had the lowest maize seed percentage germination of 44%. Similar observation was made by Ullmann et al., (2015) in evaluation of sweet sorghum seeds in which a reductionin in germination was recorded , especially at temperatures above 40 °C. As suggested by Afrakhteh et al. (2013); Menezes et al. (2012), and also observed in this study, this could be attributed to the high drying temperature at the upper level (L4) resulting in the formation of stress cracks in the seed coat and microfissures in the cotyledons thereby affecting the quality of the seeds.

However, maize dried at the lower levels (L1-L3) of the SBHD did not significantly reduce the germination potential of the grains as the recorded percentage germination of 61, 64 and 77% (L3, L2 and L1 respetively) were close or above the acceptance percentage germination of 70% recommended by the Plant Protection Act (1976). It was observed that, a 10 ˚C drop in drying temperature across the levels from L4 to L1, led to about 33% increase in germination rate of maize seeds. Similar observations were made by Kaaya and Kyamukangire, (2010), who reported that, drying maize using a biomass-heated convection dryer did not significantly reduce germination potential. Agona et al., (1998), also reported that grain dried using the natural convection dryer technology is good for seed production.

The suitability of the solar biomass hybrid dryer for the production of seed maize was investigated. The dryer has the potential to be utilised for drying maize grains for seed on commercial basis but users are encouraged to use the lower drying shelves; Level 1 through to Level 3 since maize grains dried at these levels met the standard commercial limit recommended for sale of maize seeds in Ghana. Moreover, the upper level (level 4) could be potentially utilized for drying maize grains for food or feed.

Acknowledgement

The authors express sincere gratitude to the, USDA Foreign Agricultural Service through its Scientific Cooperation Research Program for the financial support for research.

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Evaluation of AgroZ Hermetic Storage Bag against insect pests on stored maize

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DOI 10.5073/jka.2018.463.013